A Giant Glitch in PSR 131.757-24

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ABSTRACT

One of the largest known glitches has been detected in the young pulsar PSR 131757-24. The glitch occurred around MJD 49476 *and* was characterized by a fractional increase in rotation rate of 2 x 10 6. It was followed by a small exponential-like relaxation with a timescale of ~40 days, together with a longer term recovery. Such large glitches have been seen in only about 6 other pulsars of the 700 presently known. The size of the glitch and the post-glitch behaviour are similar to those of other pulsars of the same age. In this pulsar, it seems that about 1.5% of the angular momentum of the pulsar is released to the crust of the neutron star erratically, suggesting that at least this fraction of the moment of inertia of the star is in the form of superfluid neutrons.

1 INTRODUCTION

PSR 111757-24 (PSR J 1801- 2451) was discovered during a search for pulsars associated with supernova remnants (Manchester, D'Amico & Tuohy 1985). It has a short *period,* 125 ms, a characteristic age of only 15,500 yr (Manchester et al. 1991) and is located at the extreme edge of the compact nebula G5.27- 0.90, which appears to be associated with the supernova remnant G5.4 - 1.2 (Manchester et al. 199]; Frail & Kulkarni 1991). It seems that the pulsar is responsible for the excitation of the compact nebula, and, by inference, both are moving at high velocity away from the remnant, although no direct confirmation of the direction of motion has yet been made.

Glitches are rare, occurring in only a few percent of the known pulsar population. Pulsars with characteristic. ages of 10,000 50,000 yr are often found to display large glitches, while both younger and older ones show occasional mall glitches or none at all (McKenna & Lyne 1 990; Lyne 1992; Kaspi et al. 1994). For more than four years, PSR B1 757-24 has been monitored using the 76-in Jodrell Bank, 64-m Parkes and 43-m Green Bank radio telescopes. The pulsar displayed no evidence of glitch activity, but showed considerable timing noise, as well as a large positive value of the frequency second derivative, suggesting that perhaps the pulsar was recovering from a. glitch suffered prior to the commencement of the observations. Here we report further timing observation which show the occurrence of a. very large glitch in April 1994.

2 OBSERVATIONS

observations at the 64-m Parkes and 76-m Jodrell Bank radio telescopes used cryogenic, dual-channel receivers. At Parkes, the two channels were sensitive to orthogonal linear polarisations at a central observing frequency of 1 520 MI] z. The signals were filtered in a 2 x 64 x 5 MHz multichannel filterbank, detected and low-pass filtered. After summing the orthogonal polarisations the signals were sampled at 1.2 ms intervals and recorded on In agnetic tape. The data from different frequency channels were subsequently combined with appropriate delays to provide dedispersed time sequences which were then folded at the pulsar's nominal topocentric period, producing a profile integrated over an interval of a few minutes.

At Jodrell Bank, the channels were sensitive to the two hands of circular polarisation at central observing frequencies close to 1404 or 1610 MHz. The signals were filtered in a 2 x 32 x 1 MHz multichannel filterbank, detected, added in polarisation pairs, dedispersed and folded at the nominal topocentric period on-line. A single observation produced 6 profiles, each resulting from an integration over about 2 minutes. These were later added together to form a single time-tagged pulse profile.

At Green Bank, the 140ft telescope was used at frequencies around 800 and 1400 MHz, using the system described by Arzoumanian et al. (1994). orthogonal polarisations were analysed in a digital Fourier transform spectrometer which produced 256 or 512 spectral channels covering total bands of 20 or 40 MHz respectively. After summing in polarisation pairs, each spectral channel was synchronously averaged into 128 phase bins covering the. pulse period and subsequently combined with appropriate delays to provide a single dedispersed profile every 2-3 minutes.

Arrival times for the pulses were obtained by cross-correlation of the profiles with a standard, low-noise template. These topocentric arrival times were corrected to the barycentre of the Solar System using the JPL ephemeris DE200 (Standish 1982) and the nominal position of the pulsar, namely RA(J2000) = $18^h 01^m 00^s.223$, Dec(J2000) = $-24° 51' 27''.14$ (Frail & Kulkarni 1991). Arbitrary but fixed delays between the observatories were removed prior to the global fit.

Observations of typically 5 15 minutes duration were conducted over a 5-year period with separations of between about 1 day and 2 months. The rotational frequency of the pulsar was obtained by performing local fits to the arrival times over intervals of between 3 and 15 days. Fig. 1 a. shows the rotational frequencies versus time for the full data set, while Fig. 1 b shows the frequency after subtraction of the mean frequency at MJD 49476 and a constant value of the first derivative. While the effect of the glitch is small compared with the normal slow- down over the 5 years of observation (Fig. 1 a), it is clearly seen in Fig. 1 b and occurred sometime during April 1994, The last observation prior to the glitch was obtained at Jodrell Bank on MJD 49470, and the first observation after the glitch at Parkes on MJD 49482. The main effect of the glitch is a spire up in frequency with $\Delta\nu_o/\nu_o \sim 2 \times 10^{-6}$, making this among the largest glitches ever observed, the record being just over twice this value (Lyne 1992). The large size of the glitch and the 12-day interval between observations prevented extrapolation of pre-glitch and post-glitch pulse arrival time ephemerides without pulse period ambiguities, so that we can only deduce that the glitch occurred sometime between the two dates. The glitch is followed by only a modest subsequent relaxation.

We have performed a series of fits of slowdown models to the arrival time data and have quantified the glitch in ‘l’able 1 which contains the pre-glitch values of the frequency, ν_o, and its first two derivatives extrapolated to the epoch of the glitch, the analogous post-glitch values, the instantaneous changes at the glitch, and the parameters of the subsequent relaxation. ‘J’here is a rapid quasi-exponential decay occurring during the first 100 days after the glitch. The observed post-glitch frequency residuals AU can therefore be described as a function of the time, t, elapsed since the epoch of the glitch, relative to the pre-glitch ephemeris:

$$\Delta\nu(t) = \Delta\nu_p + \Delta\dot{\nu}_p t + \Delta\ddot{\nu}_p t^2/2 + \Delta\nu_1 e^{-t/\tau_1} . \qquad (1)$$

The long-term post-glitch relaxation fit given in Table 1 shows that $\Delta\nu_p$ = 15.86(1) μs and $\Delta\dot{\nu}_p$ = 30(2) Hz s^{-1} and includes an exponential of amplitude $\Delta\nu_1$ = 0.08 ± 0.03 μHz, with a characteristic time of τ_1 = 423 14 days. This rapid decay is also clearly seen in Fig. 1c which shows the variation of the frequency first derivative, obtained from local fits to the arrival times over intervals of typical length 50 100 days. This diagram also shows a long term relaxation following the glitch. While there is substantial timing noise, typical of young pulsars, the present trend in the derivative since the glitch mimics that just following the start of observations, strongly suggesting that a glitch occurred just before that time, as speculated by Manchester et al. (1991).

	Fit Interval (MJD)	ν (s^{-1})	$\dot{\nu}$ (10^{-15} s^{-2})	$\ddot{\nu}$ (10^{-24} s^{-3})	Residual (μs)
Pre-glitch	4935049470	8.006939 574(6)	8177.5(14)	- 220(220)	125
Post-glitch	49482-49608	8.006955 509(3)	8223.0(12)	1930(200)	132
Glitch increment		0.000015 935(7)	46(2)	2150(300)	
Long-term	49482-49950	8.006955 432(12)	8207(1)	200(40)	510

Table 1. Pre-glitch, post-glitch, glitch and long-term relaxation parameters for the glitch in PSR B1 757-24, all of which are referred to the mid-point of the range of possible glitch epochs, MJD 49476.000. The long-term fit includes an exponential of amplitude 0.08(3) μHz, with a characteristic time of 42(14) days (see Equation 1). The r.m.s. timing residuals for each fit are given in the last column. The quoted errors in parentheses are twice the formal errors in the last quoted digit, inferred from a least squares fit to the times of arrival.

3 IJISC1JSS1ON

The size of the glitch in rotational frequency is similar to those of some glitches in other pulsars with ages of 10,00050,000 years, and it seems that the interval between such glitches is probably a few years also. We note that the glitch spin-up of 16 μHz is ~1 .5% of the slowdown occurring in the ~ 4 years since the previous glitch event which probably occurred just before timing observations of this pulsar began. 'l'his suggests that about 1.5% of the angular momentum flowing from the inside of the neutron star to the crust is not transferred smoothly, but suddenly, possibly in the catastrophic unpinning of neutron superfluid vortices (Baym et a.]. 1969; Alpar et al. 1981). This value is very similar to that obtained for other pulsars, inclic.sting that at least 1.5% of the moment of inertia of the neutron star is carried by superfluid neutrons (Lyne 1 992; Lyne, Shemar & Smith 1996).

Glitch behaviour, though of relevance to the study of the neutron star interior, unfortunately renders long-term timing observations of little use for determining accurate astrometric parameters such as the position and proper motion, crucial in this case for assessing the association of the pulsar with the supernova remnant G5.41.2. We also note that such a determination is made even more difficult by the high level of timing noise (Fig. 1 c), substantially greater than that seen in other pulsars of similar age (Shemar & Lyne 1996). The issue of its position will most likely be settled using interferometric techniques.

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Figure Caption

Fig.1a) 'l'he rotational frequency, ν, of PSR 111757-24 over a. 5-year period, b) with a frequency of value 8.006940216 Hz on MJD 49476 and the effects of a constant first derivative of value 8175.8 x 10^{-15} Hz s^{-1} subtracted and c) the frequency derivative $\dot{\nu}$. In each diagram, the epoch of the glitch is indicated by an arrow. Most of the measurement errors are smaller than the size of the symbols.

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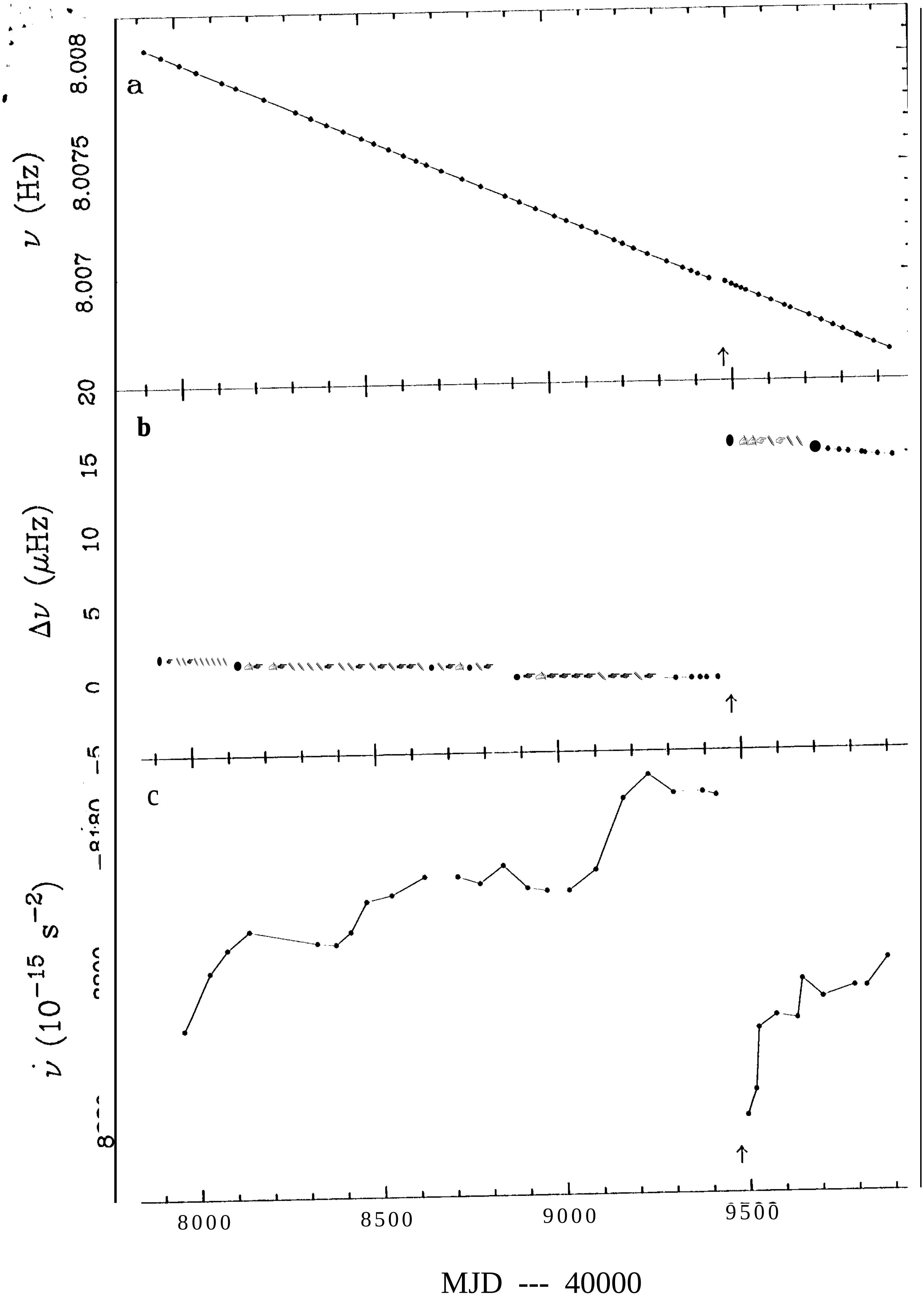

a
b
c
8.008
8.0075
8.007
ν (Hz)
20
15
10
5
0
−5
Δν (μHz)
ν̇ (10^−15 s^−2)
8000
8500
9000
9500
MJD --- 40000